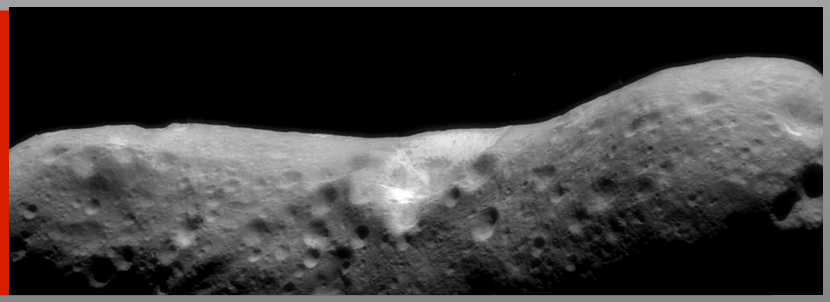
Near Earth Asteroid Rendezvous



First Launch of Discovery Program

Andrew Cheng (NEAR Project Scientist)

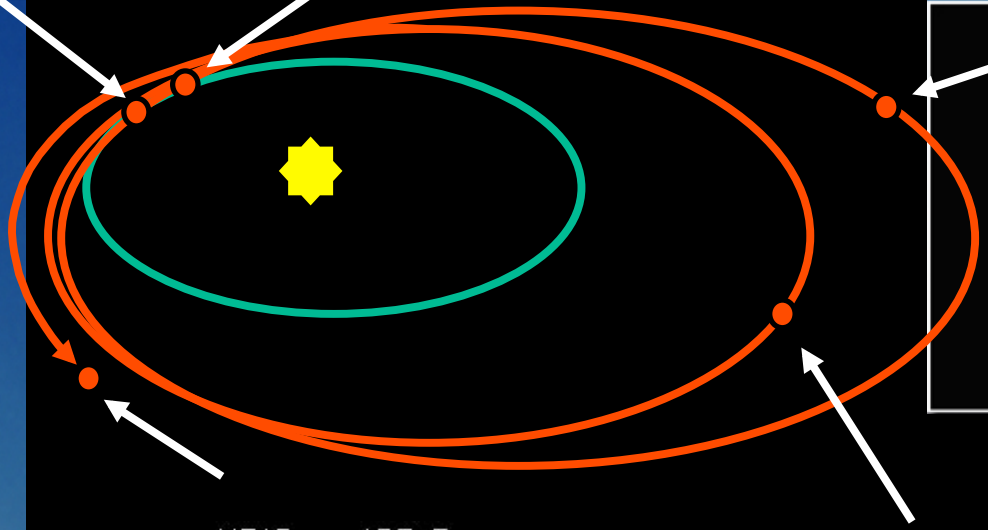
Johns Hopkins University

Applied Physics Laboratory

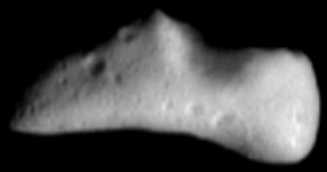
Near Earth Asteroid Rendezvous

Launch
Feb 1996

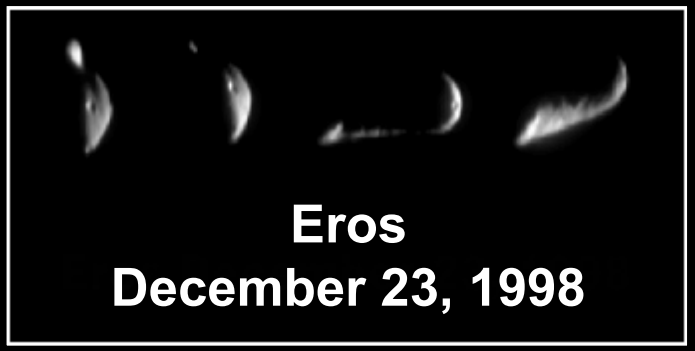
Earth swingby



NEAR – 433 Eros

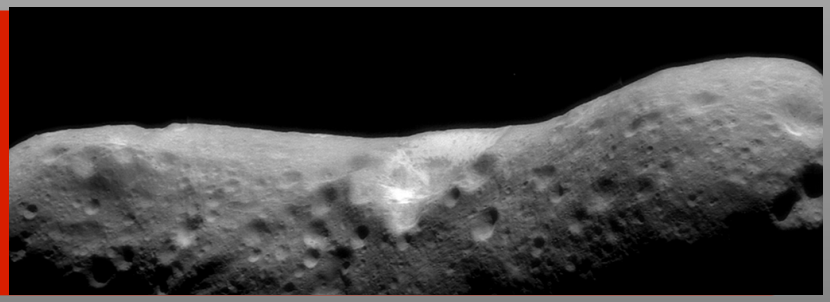


Feb 12 2000 00:45:00



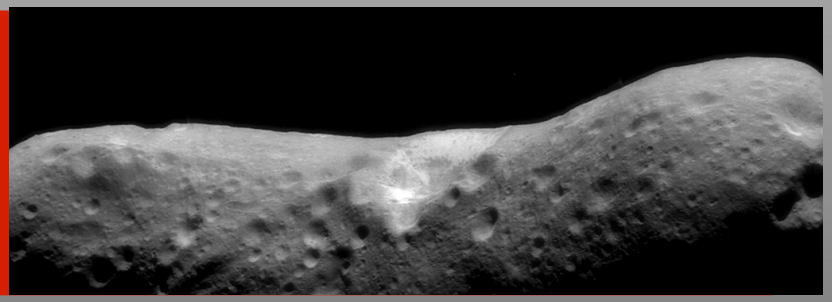
Eros 1998 and 2000

NEAR



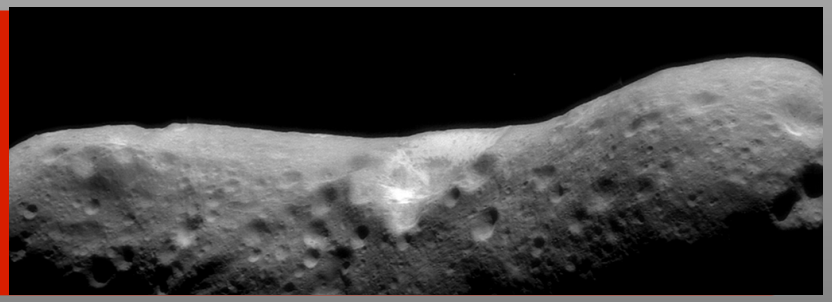
- The first asteroid mission
- The first spacecraft visit to a C-type asteroid (flyby of 253 Mathilde)
- The first asteroid rendezvous (433 Eros)
  - First orbital operations around a small, irregular body
- The first asteroid landing (433 Eros)

More "firsts"



- Programmatic and institutional firsts
  - First planetary mission at APL (also a first for NASA)
- First use of internet for internal and external project communications as well as outreach
  - A.F. Cheng blog, NEAR image of the day
- First missions with open data policy requirements and archive requirements to the Planetary Data System

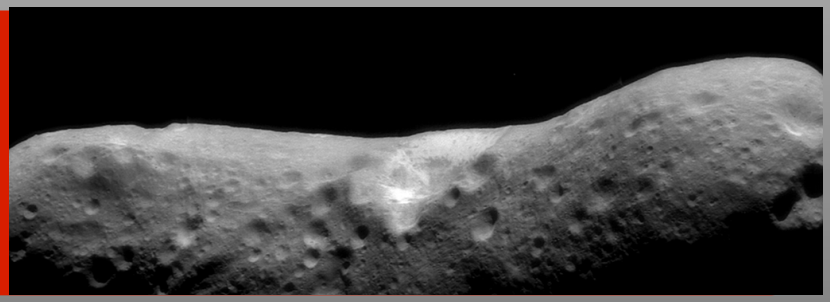
"faster, cheaper, better"



- NEAR: a new way of doing business, at lower cost, with acceptable risk

	Discovery Requirement	NEAR Performance	
Development Time	<36 mo	<27 mo	*Faster*
Cost to Launch +30 days (FY-92 $)	<$150M	<$112M	*Cheaper*
Spacecraft and Payload	Acceptable risk Limited scope science	Highly redundant spacecraft Comprehensive payload	*Better*
Launch Vehicle	Delta equivalent or smaller	Delta 7925	

Focused Mission



Near Earth Asteroid Rendezvous

Measurement Objectives

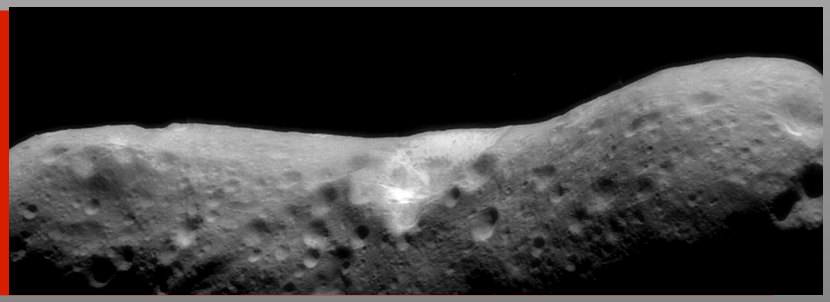
- **Bulk Properties**

shape	gravity field
mass	spin state
density	magnetic field

- **Surface Properties**
  - Elemental and mineralogical composition
  - Heterogeneity of structural and compositional units
  - Physical, geological and morphological characteristics

[original slide scanned from hard copy which predates Powerpoint]

Management Principles

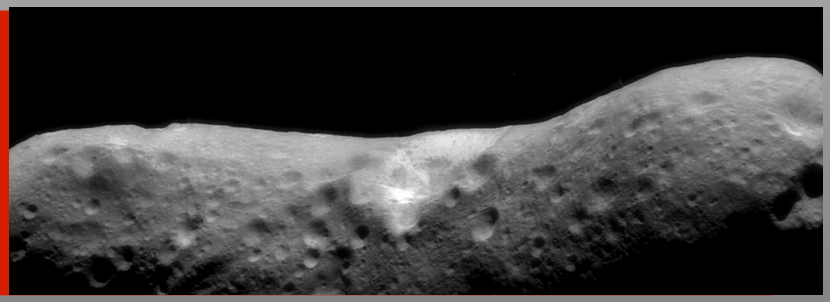


Practices for Inexpensive, Short Development Cycle Spacecraft

(a'la JHU/APL)

- Schedule from start to launch must be $\lesssim$ 36 months
- Establish small, experienced technical team with authority to do mission
- Design spacecraft and instruments to cost
- Use lead engineer method for all subsystems
- Reliability and redundancy must be designed-in (not expensive)
- Have R&QA engineer report directly to project manager
- Single agency manager to interface with contractor

Facility Instruments



Near Earth Asteroid Rendezvous

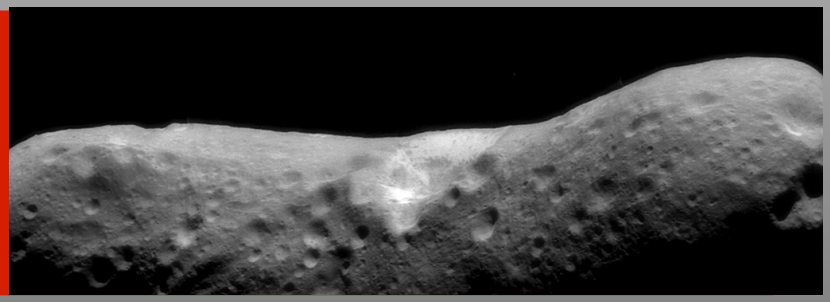
Facility Instrument Characteristics

Visible Imager	95 x 161 μr resolution 2.25° x 3° FOV 8-position filter wheel
X-ray/γ-ray Spectrometer	Al, Mg, Si, Fe, Ti, Ca U, Th, K
NEAR IR Spectrograph	~0.8-2.7 μm spectral range spectral resolution 22/44nm
Magnetometer	sensitivity <1 nT
Laser Altimeter*	range 50 km Resolution 6 m
Radio Science*	two-way Doppler to 0.1 mm/s

*engineering subsystems

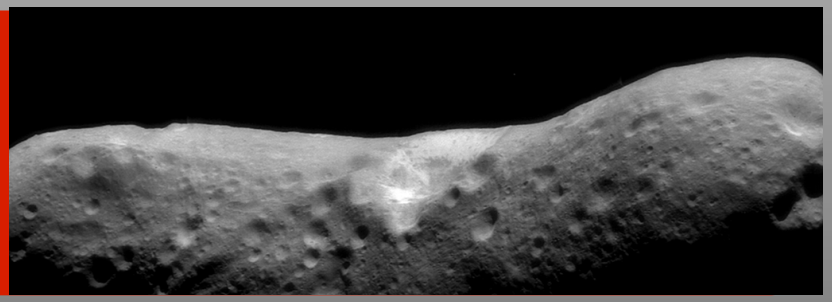
[scanned original slide with ancient typos]

NEAR Implementation



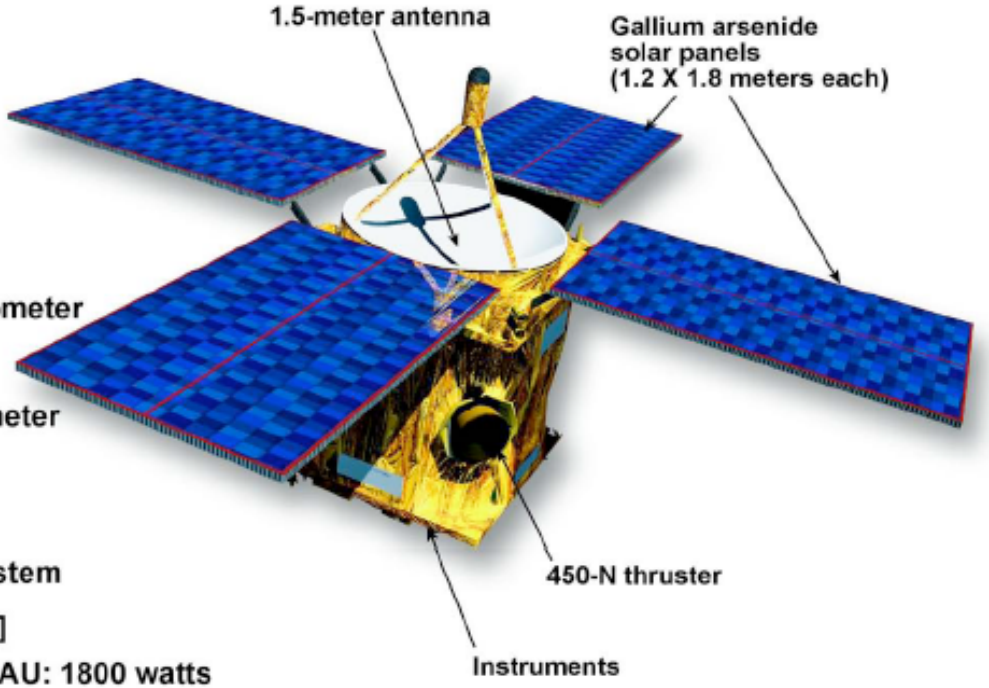
- **APL responsible for project management**
- **APL spacecraft**
- **APL provided facility instruments**
  - NASA selected facility instrument science team
  - NASA selected a participating scientist team
- **APL responsible for mission operations**
- **JPL responsible for navigation and DSN support**

Simple Spacecraft

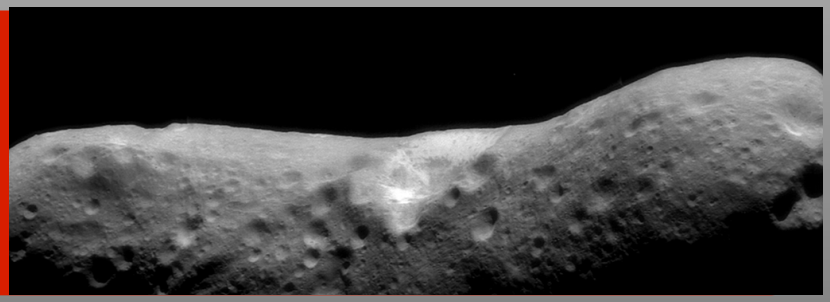


- Three-axis stabilized
- Total weight: 805 kg
  - Propellants: 320 kg
  - Experiments: 60 kg
- Science payload
  - Multispectral imager
  - Near-infrared spectrometer
  - X-ray spectrometer
  - Gamma-ray spectrometer
  - Laser altimeter
  - Magnetometer
- Dual-mode propulsion system

  [ΔV capability: 1450 m/s]
- Solar array power @ 1.00 AU: 1800 watts
- Two solid-state recorders: 1.7 x 10^9 bits



Schedule set in 1992
and followed through launch

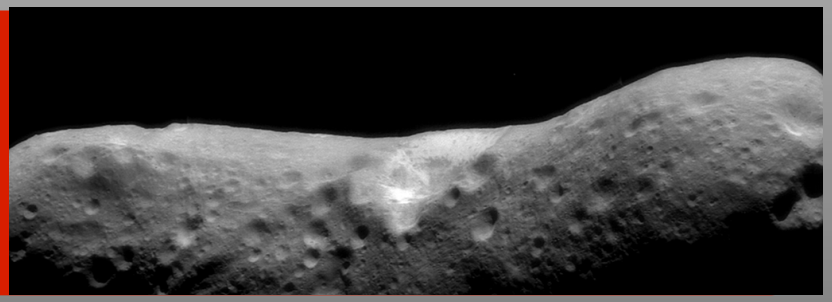


Near Earth Asteroid Rendezvous

Preliminary Schedule
EROS MISSION

CALENDAR YEAR	93	94	95	96
INSTRUMENT SELECTION	Δ			
CONCEPTUAL DESIGN REVIEW		Δ		
PRELIMINARY DESIGN REVIEW		Δ		
CRITICAL DESIGN REVIEW		Δ		
MISSION READINESS REVIEW			Δ	
INSTRUMENT/ S/C INTERFACES		▨		
PRELIMINARY LAYOUTS		▨		
DETAIL DESIGN		▨		
FABRICATION			▨	
SUBSYSTEM TEST			▨	
SPACECRAFT LEVEL TEST			▨	
LAUNCH				Δ FEB

How it was done

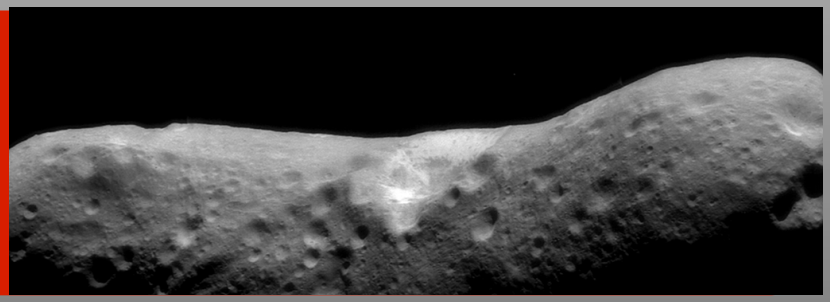


Near Earth Asteroid Rendezvous

Technical Approach

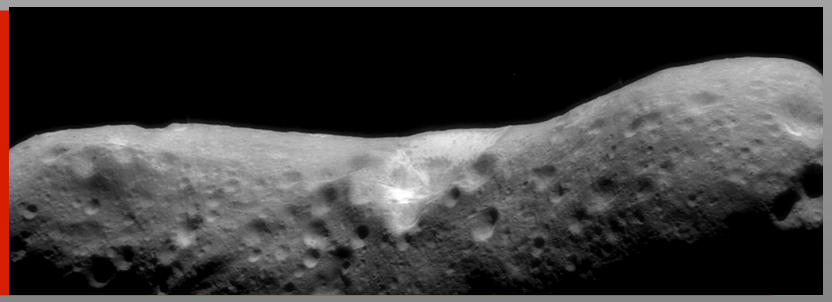
- **Approach suited to Discovery Mission**
  - Optimized to schedule
  - Consistent with program cost, propellant mass fraction
- **Design to schedule approach**
  - Modularity in propulsion system
  - Distributed architecture
  - Large (50%) use of off-the-shelf components
  - 1533 data bus
  - Qualification of subsystems prior to spacecraft delivery

Mission Milestones



- Launch (February 17, 1996)
- Mathilde Encounter (June 27, 1997)
- Earth Flyby (January 23, 1998)
- Eros Flyby (December 23, 1998)
- Eros orbit insertion (February 14, 2000)
- Eros landing (February 12, 2001)
- Landed science operations through end of mission (February 28, 2001)

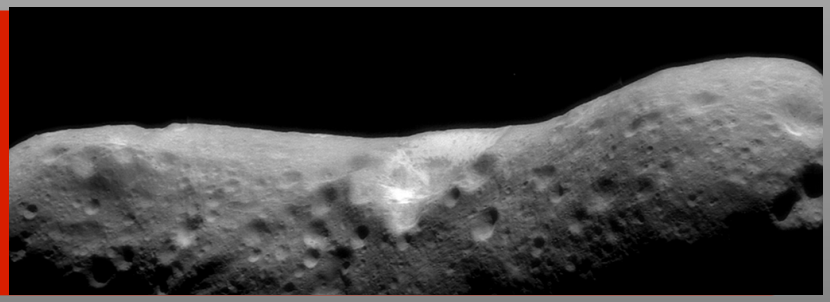
One very bad day



Aborted Rendezvous Burn
December 20, 1998

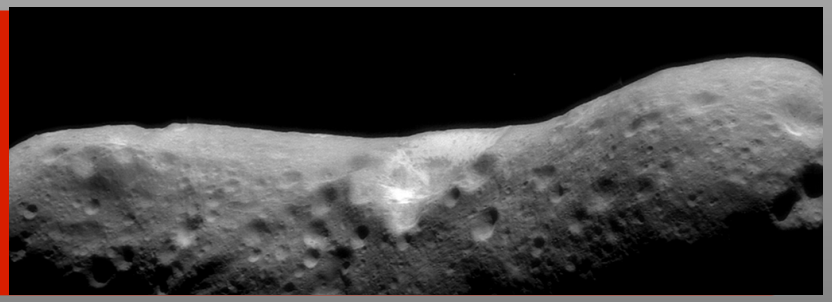
- On board autonomy system shut down main engine at onset
  - Accelerometer normal to thrust vector
- Spacecraft went into "Safe Mode" as planned
- Spacecraft tumbled
  - Expended 28 Kg. of fuel; not as planned and still unexplained
- Spacecraft went deeper to "Sun Safe Mode" as solar arrays exceeded angle to sun
- Recovered spacecraft 27 hours later, as planned
- Eros flyby on December 23,1998
- Successful main engine burn on January 3, 1999
- Rendezvous with Eros delayed until February 2000

Mission Operations learned in flight



- **Concept of operations developed after launch for a small team**
  - There was no good model for NEAR (the last orbital mission was Galileo)
- **Little or no simulation of orbital operations**
  - No previous orbital mission around an irregularly shaped, small object
  - Navigational accuracy could not be predicted
  - Spacecraft predicted to safe often (which did NOT happen)
- **Eros flyby was in some sense a blessing**

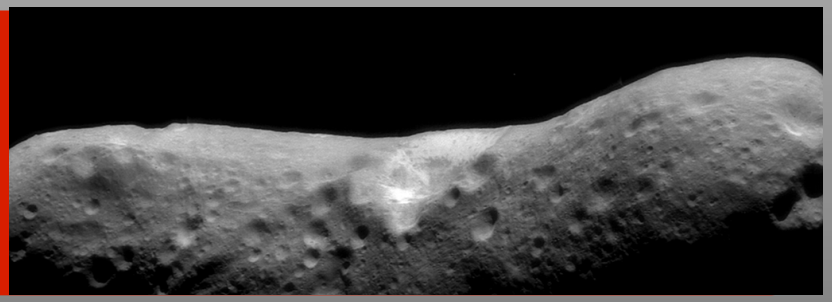
Mission Success



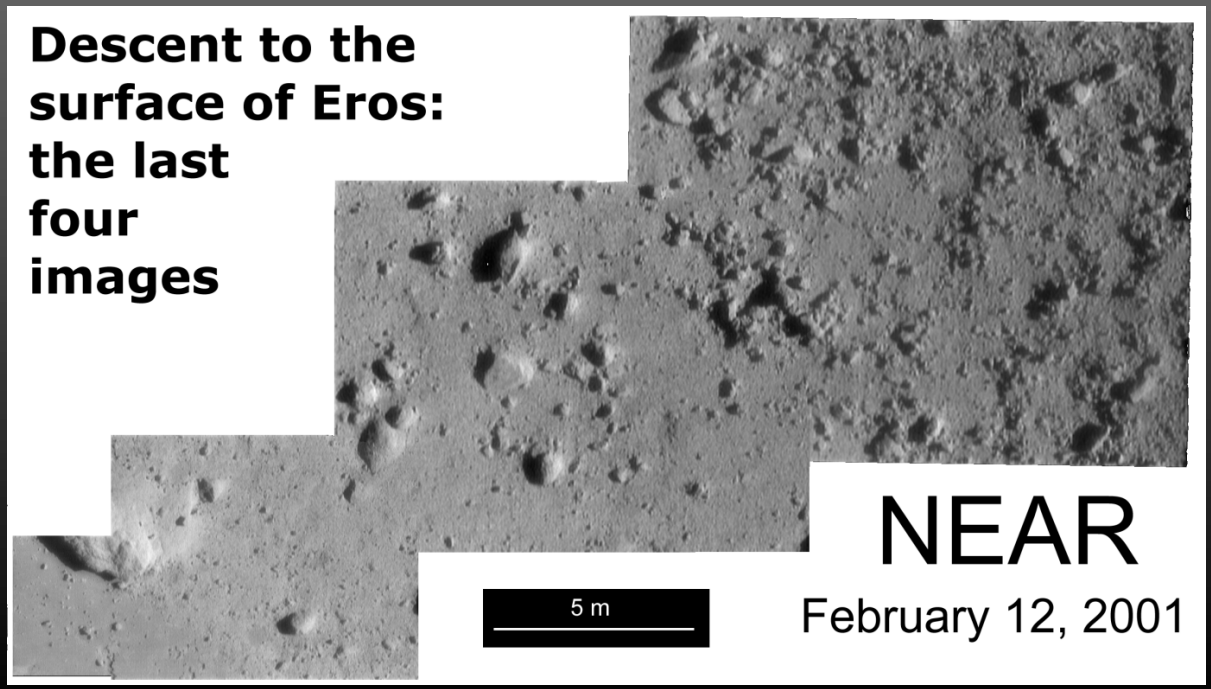
Near Earth Asteroid Rendezvous

- **Feb 2001 - mission completed with landing on 433 Eros**
  - All data in PDS, September 2001
- **Science Objectives fulfilled**
- **Mission Extras**
  - Mathilde fly-by
  - Two low altitude passes of Eros surface (< 5km)
  - Landing
- **Final Cost within 3% of total mission cost given to NASA in 1994**
  - Includes thirteen month delay due to burn anomaly, December 1998

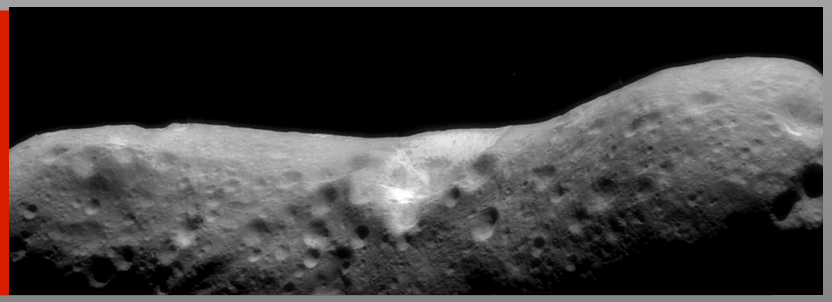
The First Asteroid Landing



- Spacecraft not designed for landing
- Touchdown at ~1.6 m/s, 316 million km from Earth
- Spacecraft acquired scientific data for two weeks after landing

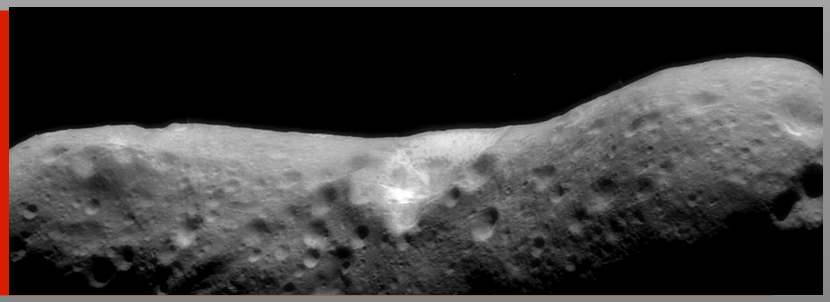


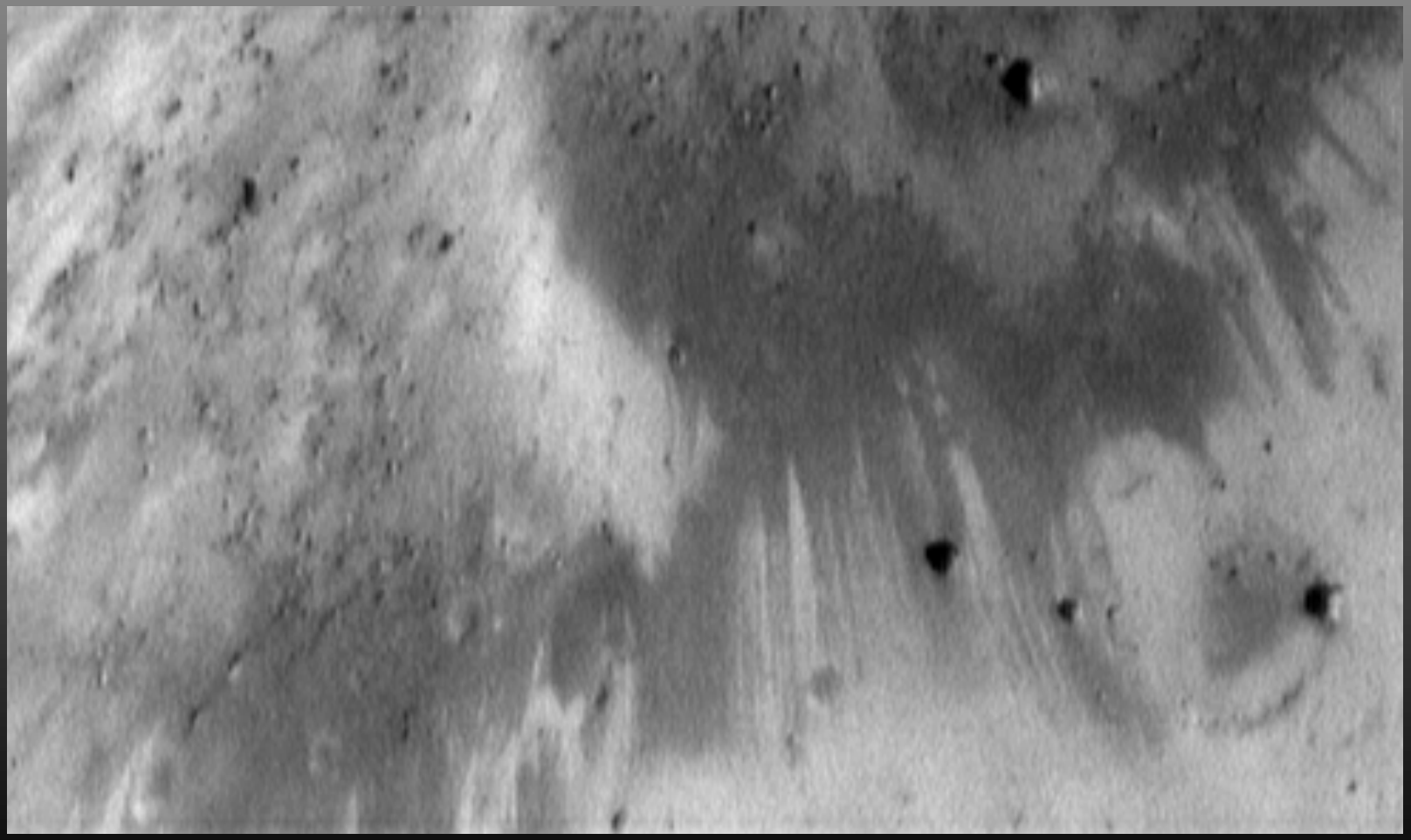
Science Success



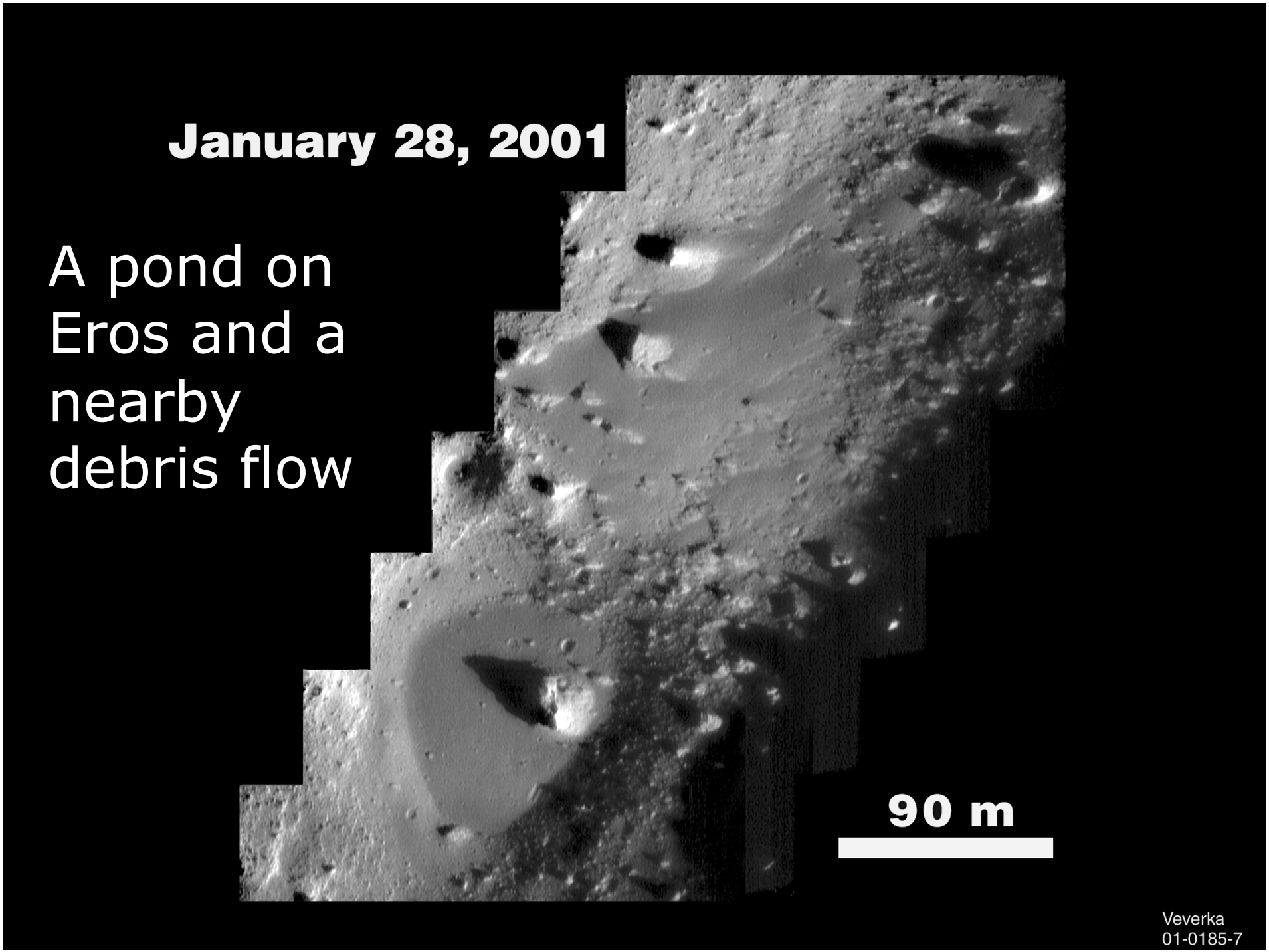
- All science objectives met or exceeded
- More science and data returned than originally planned
  - More than 10x number of images
  - Two low altitude flybys (under 5 km)
  - Landing and science operations on the surface
- No major spacecraft anomalies at Eros

Geologically Active Surfaces

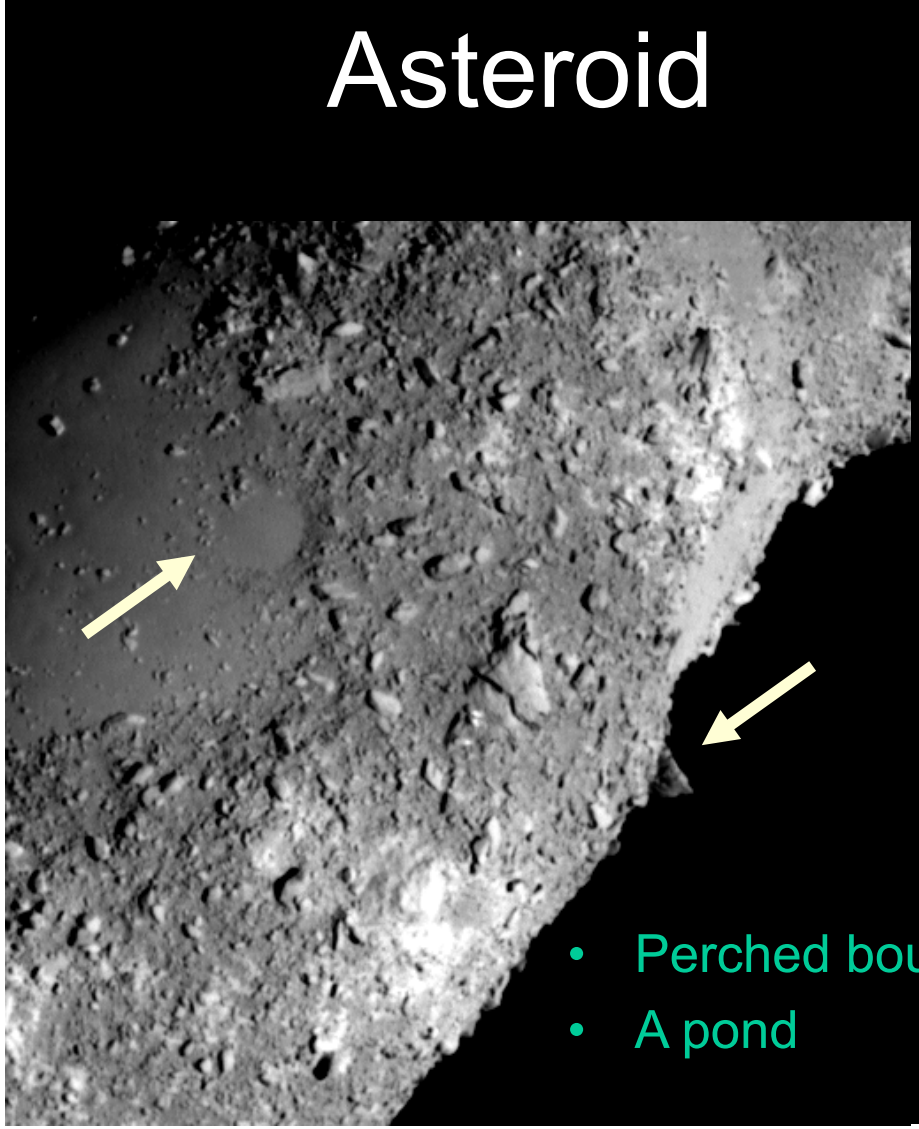




Lobate, downslope-oriented bright streaks at 2.5 m/px in crater Selene [19]


January 28, 2001
A pond on Eros and a nearby debris flow
90 m
Veverka
01-0185-7

A Completely Different Asteroid



- Perched boulders
- A pond